

A COMPARATIVE STUDY OF THE AHP AND TOPSIS METHODS  
FOR IMPLEMENTING LOAD SHEDDING SCHEME IN A PULP MILL SYSTEM

ZARINA BT HAJI IBRAHIM

A project report submitted in partial  
fulfilment of the requirement for the award of the  
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronics Engineering  
Universiti Tun Hussein Onn Malaysia

JANUARY 2014

## ABSTRACT

The advancement of technology had encouraged mankind to design and create useful equipment and devices. These equipment enable users to fully utilize them in various applications. Pulp mill is one of the heavy industries that consumes large amount of electricity in its production. Due to this, any malfunction of the equipment might cause mass losses to the company. In particular, the breakdown of the generator would cause other generators to be overloaded. In the meantime, the subsequence loads will be shed until the generators are sufficient to provide the power to other loads. Once the fault had been fixed, the load shedding scheme can be deactivated. Thus, load shedding scheme is the best way in handling such condition. Selected load will be shed under this scheme in order to protect the generators from being damaged. Multi Criteria Decision Making (MCDM) can be applied in determination of the load shedding scheme in the electric power system. In this thesis two methods which are Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) were introduced and applied. From this thesis, a series of analyses are conducted and the results are determined. Among these two methods which are AHP and TOPSIS, the results shown that TOPSIS is the best Multi criteria Decision Making (MCDM) for load shedding scheme in the pulp mill system. TOPSIS is the most effective solution because of the highest percentage effectiveness of load shedding between these two methods. The results of the AHP and TOPSIS analysis to the pulp mill system are very promising.

## ABSTRAK

Kemajuan teknologi telah menyokong manusia untuk merekabentuk dan mencipta peralatan dan peranti yang bermanfaat. Peralatan ini membolehkan pengguna menggunakan sepenuhnya peralatan tersebut dalam pelbagai aplikasi. Kilang kertas adalah salah satu industri berat yang menggunakan jumlah elektrik yang besar untuk pengeluarannya. Oleh kerana itu, peralatan yang tidak boleh beroperasi dengan baik boleh menyebabkan kerugian yang besar kepada syarikat. Khususnya, kerosakan pada mana-mana penjana akan menyebabkan penjana yang lain akan terlebih beban. Dalam masa yang sama, beban seterusnya akan dikeluarkan sehingga penjana tersebut mampu untuk membekalkan kuasa kepada beban yang lain. Apabila kerosakan telah diperbaiki, skim penumpahan beban akan dimatikan. Maka, skim penumpahan beban adalah kaedah terbaik untuk mengendalikan keadaan tersebut. Beban tertentu akan dikeluarkan di dalam skim ini dalam usaha melindungi penjana daripada rosak. *Multi Criteria Decision Making(MCDM)* boleh digunakan untuk menentukan skim penumpahan beban dalam sistem kuasa elektrik. Di dalam tesis ini iaitu *Analytic Hierarchy Process (AHP)* dan *Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)* diperkenalkan dan digunakan. Daripada tesis ini, beberapa siri analisis dijalankan dan keputusan akan ditentukan. Daripada dua kaedah ini iaitu AHP and TOPSIS, keputusan menunjukkan TOPSIS adalah pilihan terbaik *Multi Criteria Decision Making(MCDM)* untuk skim penumpahan beban di dalam sistem kilang kertas. TOPSIS adalah memberi penyelesaian yang paling berkesan kerana mempunyai peratus tertinggi keberkesanan penumpahan beban antara dua kaedah tersebut. Keputusan analisis daripada AHP and TOPSIS dalam sistem kilang kertas adalah mempunyai kejutuan yang tinggi.

## CONTENTS

<b>THESIS STATUS APPROVAL</b>	
<b>EXAMINER'S DECLARATION</b>	
<b>TITLE</b>	<b>i</b>
<b>DECLARATION</b>	<b>ii</b>
<b>DEDICATION</b>	<b>iii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iv</b>
<b>ABSTRACT</b>	<b>v</b>
<b>ABSTRAK</b>	<b>vi</b>
<b>CONTENTS</b>	<b>vii</b>
<b>LIST OF TABLES</b>	<b>ix</b>
<b>LIST OF FIGURES</b>	<b>x</b>
<b>LIST OF SYMBOLS AND ABBREVIATIONS</b>	<b>xii</b>
<b>LIST OF APPENDICES</b>	<b>xiii</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Project Background	1
1.2 Problem Statement	2-5
1.3 Project Objective	5
1.4 Project Scope	5
<b>CHAPTER 2 LITERATURE REVIEW</b>	<b>6</b>
2.1 Load Shedding	6-7
2.2 Analytical Hierarchy Process (AHP)	7-12
2.3 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	12-13
2.4 Pulp Mill Electrical System General Information	14-15
2.4.1 Island Mode	16
2.4.2 Parallel Mode	16-17

<b>CHAPTER 3</b>	<b>METHODOLOGY</b>	<b>18</b>
3.1	Analytic Hierarchy Process (AHP)	18-26
3.2	Technique For Order Preference By Similarity to Ideal Situation (TOPSIS)	27-30
3.3	Load Shedding Scheme in Pulp Mill System	31-35
<b>CHAPTER 4</b>	<b>RESULT AND ANALYSIS</b>	<b>36</b>
4.1	Data Analysis	36-37
4.2	AHP Analysis Method	37-58
4.3	TOPSIS Analysis Method	59-74
4.4	Discussion	75-80
<b>CHAPTER 5</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>81</b>
5.1	Conclusion	81-82
5.2	Recommendation	82-83
	<b>REFERENCES</b>	84-87
	<b>APPENDICES</b>	88



PTTA UTHM  
PERPUSTAKAAN TUNKU TUN AMINAH

## LIST OF TABLES

Table 1.1	Statistics of transmission system tripping with a load loss of 50MW and above for the first half year of 2010	3
Table 2.1	The fundamental scale of absolute numbers	10
Table 2.2	Summarised information for research projects related to AHP	12
Table 2.3	Summarised information for research projects related to TOPSIS	13
Table 3.1	Table of random index (Saaty, 1980)	19
Table 3.2	The pulp mill loading estimation	34
Table 4.1	Pair-wise comparison table matrix	38
Table 4.2	Product of pair-wise comparison matrix	38
Table 4.3	Root of the product for criteria	39
Table 4.4	Pair-wise comparison matrix (alternatives) for operating load	43
Table 4.5	Pair-wise comparison matrix (alternatives) for area power	44
Table 4.6	The 15th root of product for alternatives in operating load	45
Table 4.7	The 15th root of product for alternatives in area power	46
Table 4.8	Matrix multiplication between criteria and alternatives	54
Table 4.9	Overall performance of AHP for pulp mill system	55
Table 4.10	Criteria data	63
Table 4.11	Relative closeness calculation	69
Table 4.12	Relative closeness	70
Table 4.13	Load ranking using TOPSIS	71
Table 4.14	The order of load shedding for pulp mill system	76
Table 4.15	The percentage effectiveness of load shedding for pulp mill system	78

## LIST OF FIGURES

Figure 1.1	Number of Transmission System Tripping in Peninsular Malaysia with a Load Loss of 50MW and above for first half year of 2008 – 2010 and in the year 2007-2009	3
Figure 1.2	Causes of unscheduled electricity supply interruptions in Peninsular Malaysia [3]	4
Figure 1.3	Maximum demand and installed generation capacity in Peninsular Malaysia for the first half year of 2010	4
Figure 2.1	The Analytic Hierarchy Process (AHP) scheme	8
Figure 3.1	Flowchart for AHP Method	23
Figure 3.2	Step 1 in AHP method	24
Figure 3.3	Step 2 in AHP method	25
Figure 3.4	Step 3 in AHP method	26
Figure 3.5	Flowchart for TOPSIS method	30
Figure 3.6	The part of the electrical system in a pulp mill	32
Figure 3.7	The pulp mill electrical system analysis by using ETAP	33
Figure 4.1	Relationship between the parameter	37
Figure 4.2	Weight of Criteria	41
Figure 4.3	Percentage of weight of criteria	41
Figure 4.4	Graph for weight of alternatives in operating load	48
Figure 4.5	Graph for percentage of alternatives in operating load	49
Figure 4.6	Graph for weight of alternatives in area power	51
Figure 4.7	Graph for percentage of weight of alternatives in area power	51
Figure 4.8	Relationship between criteria and alternatives for load shedding analysis	53
Figure 4.9	Graph for overall priority of AHP for pulp mill system	56

Figure 4.10	Graph for percentage of overall performance of AHP for pulp mill system	57
Figure 4.11	Flowchart for load shedding using AHP method in pulp mill system	58
Figure 4.12	Relative closeness to ideal solution for pulp mill system	70
Figure 4.14	Graph for overall ranking for feeder in pulp mill system	72
Figure 4.15	Flowchart for load shedding using TOPSIS method in pulp mill system	73
Figure 4.19	Flow chart of TOPSIS solution procedure	74
Figure 4.20	The percentage effectiveness of load shedding for pulp mill system	79





## LIST OS SYMBOLS AND ABBREVIATIONS

$\Sigma$	-	Summation
CR	-	Consistency Ratio
RC	-	Relative Closeness
RI	-	Random Index
CI	-	Consistency Index
et al.	-	And others
AHP	-	Analytic Hierarchy Process
AP	-	Area Power
ETAP	-	Power system software
HV	-	High voltage
Hz	-	Hertz
L	-	Load
LP	-	Load power
LS	-	Load shedding
LV	-	Low voltage
AHP	-	Analytic Hierarchy Process
TG	-	Turbo Generator
TNB	-	Tenaga Nasional Berhad
ETAP	-	Power system software
SCADA	-	Supervisory Control and Data Acquisition
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
Parea	-	Area Power
Pload	-	Operating Load
$W_c$	-	weight matrix for criteria
PIS	-	positive ideal solution
NIS	-	negative ideal solution
MCDM	-	Multi Criteria Decision Making

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Fuzzy Multi-criteria Decision-making TOPSIS for Distribution Center Location Selection	88
B	Service Selection Based on Fuzzy TOPSIS Method	89



## CHAPTER 1

### INTRODUCTION

#### 1.1 Project background

Power systems are designed and operated so that for any normal system condition, including a defined set of contingency conditions, there is adequate generating and transmission capacities to meet load requirements. However, there are economic limits on the excess capacity designed into a system and the contingency outages under which a system may be designed to operate satisfactorily. For those rare conditions where the system's capability is exceeded, there are usually processes in place to automatically monitor a power system's loading levels and reduce loading when required.

The load shed processes automatically sense overload conditions, then shed enough load to relieve the overloaded equipment before there is loss of generation, line tripping, equipment damage, or a chaotic random shutdown of the system.

Thereupon, by removing a substances amount of load can ensure the remaining portion of the system operational. That remaining portion should be only the vital and most critical loads in the system. And the substances amount of load in discussed to be shed or switched off should be from any non-vital loads available in the same disturbed system [1]. By switching off that selected load, the balance between the power generated and load demand could be brought back. Hence, the skill to properly differentiate what load to be shed first and so forth is important in

achieving an ideal load shedding module. The process of differentiating can be done by ranking them in hierarchy.

Therefore in this study, the analysis outcome in interest is to remove loads by ranking them according to their priority. By earning the first rank means that the priority is less as the load shedding module aims is to ensure power continuity to only vital and most critical loads in the system. The module begins with non-vital loads shedding and follows by semi-vital loads removal. The vital loads can only be removed if the system is disturbed by large disturbances such as major generation outages.

Foremost, the analysis is begins by setting a goal and identifies the criteria. These two will frame out the shedding process. And to aid or to simplify the selecting process comprising multiple criteria condition can be chosen from the variety multi-attribute or multi-criteria decision making (MADM/MCDM) technique.

In this study, the Analytic Hierarchy Process(AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are used to as an agent searching for the best set of load to be shed in recovering the shortage of the electrical power availability. They have been known to solve problems in areas such as engineering, government, industry, management, manufacturing, personal, political, social and sports [2].

## **1.2 Problem statement**

According to the statistics provided by Suruhanjaya Tenaga [3], as shown in Figure 1.1 by practicing the load shedding the numbers of tripping events in Peninsular Malaysia were much less compared to the tripping taken by non-load shedding action. The average is null to 5.6 in 2007-2009 alone.

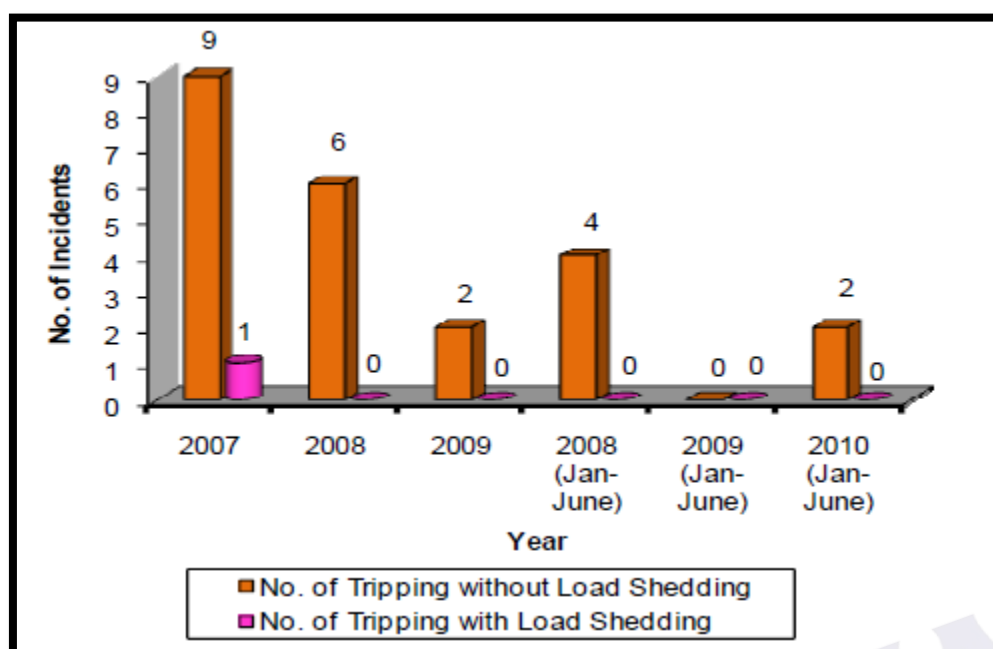


Figure 1.1: Number of Transmission System Tripping in Peninsular Malaysia with a Load Loss of 50MW and above for first half year of 2008 – 2010 and in the year 2007-2009 [3]

Table 1.1: Statistics of transmission system tripping with a load loss of 50MW and above for the first half year of 2010 [3]

Perkara / Indicators	Jan	Feb	Mar	Apr	May	June
Bilangan Pelantikan <i>No. of Tripping without Load Shedding</i>	0	1	0	0	0	1
Bilangan Lucutan Beban <i>No. of Tripping with Load Shedding</i>	0	0	0	0	0	0
Kehilangan Beban Maksimum (MW) <i>Maximum Load Loss (MW)</i>		56				61.5
Tenaga Yang Tidak Dibekalkan Semasa Pelantikan (MWj) <i>Unsupplied Energy due to Tripping (MWh)</i>		112.1				57.3
Purata Tenaga Tidak Dibekalkan Setiap Pelantikan (MWj) <i>Average Unsupplied Energy per Trip (MWh)</i>		112.1				57.3
Purata Tempoh Setiap Pelantikan (Jam:Minit) <i>Average Duration per Trip (Hour)</i>		2:00				0:56
Tenaga Tidak Dibekalkan Semasa Lucutan Beban (MWj) <i>Unsupplied Energy During Load Shedding (MWh)</i>	0	0	0	0	0	0

By referring to Table 1.1, in the first half of 2010 Peninsular Malaysia experienced tripping events only twice without load shedding action compared to none when with load shedding. A 56MW and 61.5MW loads were shed in February and June, respectively which caused a discontinuity of 112.1 MW/h and 57.3 MW/h supplied energy to the customers as seen in Table 1.1. The causes were numerous; with process and quality of works hold the majority of 56.7% in contrast to the least cause natural disaster with only 0.1% (refer to Figure 1.2). But still, they only caused two tripping events in the first six months of 2010.

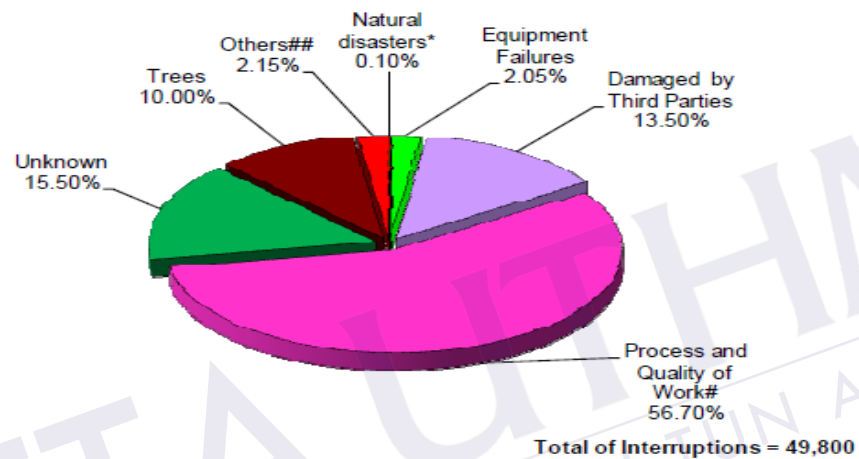


Figure 1.2: Causes of unscheduled electricity supply interruptions in Peninsular Malaysia [3]

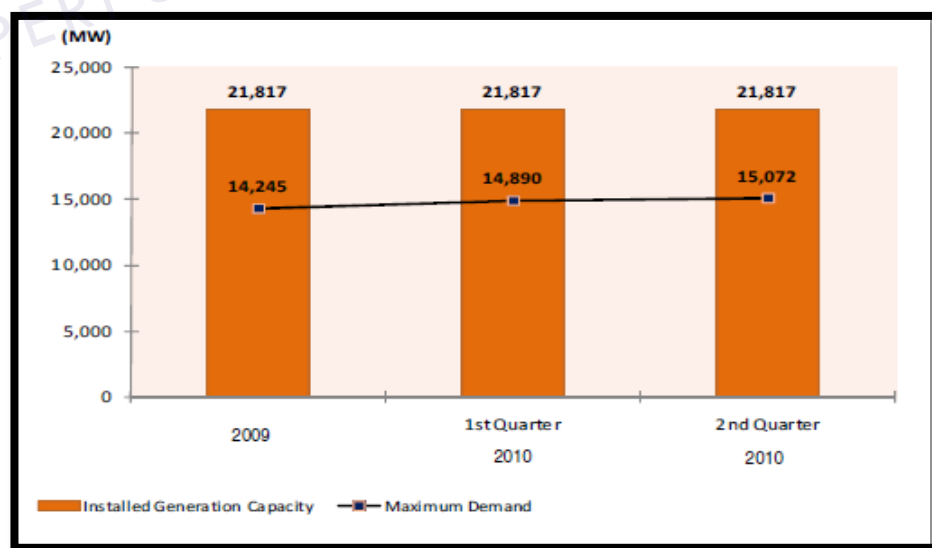


Figure 1.3: Maximum demand and installed generation capacity in Peninsular Malaysia for the first half year of 2010 [3]

Thus, by analyzing the data from Figure 1.3 can clearly explains that customers demand continues to grow with each year despite the unscheduled interruptions event. Therefore, it is the duty of Tenaga Nasional Berhad (TNB) to ensure the continuity in load feeding as the progress of the industrial and technological relies in the reliability and credibility of such companies. Any contingency that could bring catastrophic impact to the power system Peninsular Malaysia power network has to be prudently mitigated. There are many ways for the companies to mitigate the problem and among them is the famed load shedding. By far load shedding is a last-resort measure taken by the company if and only if prior precaution steps fail to balance back the supply (power generated) and demand (loads/customers).

### **1.3 Project Objectives**

There are three objectives for this project:

- a) To implement multi-criteria decision-making methods such as AHP and TOPSIS in the load shedding scheme.
- b) To evaluate AHP and TOPSIS performances for pulp mill electrical system
- c) To compare the effectiveness of multi-criteria decision making methods in load shedding scheme.

### **1.4 Project Scope**

The system study was carried out using the Microsoft Excel software application. The following salient points are taken into consideration:

- a) The system study is carried out to rank load priority for load shedding scheme as one of the defense scheme/protection system in pulp mill electrical system
- b) Only power generated and load demand were considered in this analysis
- c) The type of disturbance considered in this analysis was large contingency such as major generator outages or important power transmission line outages.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Load shedding

Load shedding is defined as an amount of load that must almost instantly be removed from a power system to keep the remaining portion of the system operational [3]. This protection action is in response to the system that was disturbed by either major generation outages or important power transmission line outages, faults, switching errors or lightning strikes which cause a generation deficiency condition and if not properly executed can lead to a total system collapse [3-4].

Thereupon, through tremendous studies it has been proven that by removing a substances amount of load can ensure a portion of the system operational. That remaining portion should be only the vital and most critical loads in the system. And the supposed loads that were shed or switched off should be from any non-vital loads available in the same disturbed system [5]. This fast mitigation helps in bringing back the balance between the power generated and load demand.

With that intention in interest, load shedding has been practiced by electric utility company around the world as early as ones could remember. It is known as the last-resort measure used by an electric utility company in avoiding a total blackout of the power system. Load shedding is common or evens a normal daily event in many developing countries where electricity generation capacity is underfunded or infrastructure is poorly managed. On the other hand, in developed countries this kind of measure is rare because demand is accurately forecasted, adequate infrastructure



investment is scheduled and networks are well managed; such events are considered an unacceptable failure of planning and can cause significant political damage to responsible governments.

## 2.2 Analytic Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a method for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria. It answers the question, “Which one?”. With AHP, the decision maker selects the alternative that best meets his or her decision criteria and develops a numerical score to rank each alternative decision based on how well each alternative meets them [6].

In AHP, preferences between alternatives are determined by making pairwise comparisons. In a pairwise comparison, the decision maker examines two alternatives by considering one criterion and indicates a preference. These comparisons are made using a preference scale, which assigns numerical values to different levels of preference. The standard preferred scale used for the AHP is 1-9 scale which lies between “equal importances” to “extreme importance” where sometimes different evaluation scales can be used such as 1 to 5 [7].

In the pairwise comparison matrix, the value 9 indicates that one factor is extremely more important than the other, and the value  $1/9$  indicates that one factor is extremely less important than the other, and the value 1 indicates equal importance. Therefore, if the importance of one factor with respect to the second factor is given, then the importance of the second factor with respect to the first is the reciprocal. The ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements [7].

Since 1977, Saaty [8] proposed AHP as a decision aid to solve unstructured problems in economics, social and management sciences. AHP has been applied in a variety of contexts: from the simple everyday problem of selecting a school to the complex problems of designing alternative future outcomes of a developing country, evaluating political candidacy, allocating energy resources, and so on. The AHP enables the decision-makers to structure a complex problem in the form of a simple

hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environment in the conflation [8].

The application of the AHP to the complex problem usually involves four major steps [8].

- (a) Break down the complex problem into a number of small constituent elements and then structure the elements in a hierarchical form.
- (b) Make a series of pairwise comparisons between the elements according to a ratio scale.
- (c) Use the eigenvalue method to estimate the relative weights of the elements.
- (d) Aggregate the relative weights and synthesis them for the final measurement of given decision alternatives [8].

The AHP is a powerful and flexible multi-criteria decision-making tool for dealing with complex problems where both qualitative and quantitative aspects need to be considered. The AHP helps analysts to organise the critical aspects of a problem into a hierarchy rather like a family tree [8].

The essence of the process is decomposition of a complex problem into a hierarchy with a goal at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy [8]. Figure 2.1 illustrates the scheme of the Analytic Hierarchy Process (AHP).

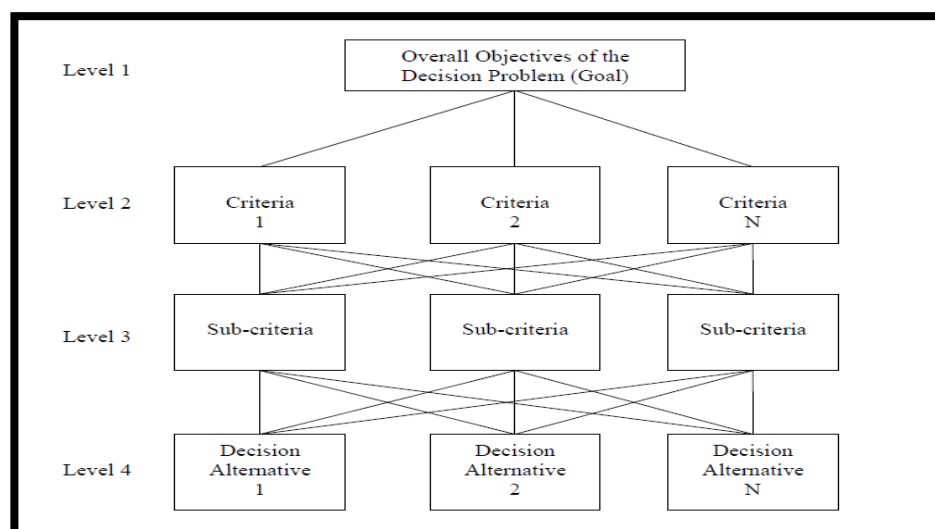


Figure 2.1: The Analytic Hierarchy Process (AHP) scheme [8]

Elements at the given hierarchy levels are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives are obtained. The entries of the final weight coefficient vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of the hierarchy [8].

A decision maker may use this vector according to his particular needs and interests. To elicit pairwise comparisons performed at a given level, a matrix  $A$  is created in turn by putting the result of pairwise comparisons of element  $i$  with element  $j$  into the position  $a_{ji}$  as given in Equation (2.1) [8].

$$A = \begin{matrix} & \begin{matrix} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & \dots & C_n \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & \dots & a_{1n} \\ a_{21} & 1 & a_{23} & a_{24} & a_{25} & a_{26} & \dots & a_{2n} \\ a_{31} & a_{32} & 1 & a_{34} & a_{35} & a_{36} & \dots & a_{3n} \\ a_{41} & a_{42} & a_{43} & 1 & a_{45} & a_{46} & \dots & a_{4n} \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & a_{56} & \dots & a_{5n} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 & \dots & a_{6n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 1 & \vdots \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & a_{n6} & \dots & 1 \end{bmatrix} \end{matrix} \quad (2.1)$$

where

$n$  = criteria number to be evaluated

$C_i$  =  $i$ th criteria, ( $i=1,2,3,\dots,n$ )

$A_{ij}$  = importance of  $i$ th criteria according to  $j$ th criteria ( $j=1,2,3,\dots,n$ )

After obtaining the weight vector, it is then multiplied by the weight coefficient of the element at a higher level (that was used as the criterion for pairwise comparisons). The procedure is repeated upward for each level, until the top of the hierarchy is reached.

The overall weight coefficient, with respect to the goal for each decision alternative is then obtained. The alternative with the highest weight coefficient value should be taken as the best alternative. The Analytical Hierarchy Process is a well-known decision-making analytical tool used for modeling unstructured problems in various areas, e.g., social, economic, and management sciences [8].

Table 2.1 shows the fundamental scale of values to represent the intensities of judgments. There are several intensities of importance. Each of the intensities of the importance is attached with the definition and explanation. Table 2.1 can be used as the reference when proceed to do the AHP analysis [9].

Table 2.1 : The fundamental scale of absolute numbers [9]

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another
6	Strong Plus	
7	Very Strong	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order to affirmation
Reciprocals of above	If activity $i$ has one of the above nonzero numbers assigned to it when compared with activity $j$ , then $j$ has the reciprocal value when compared with $i$	A reasonable assumption

A number of research projects on the application and using of analytical hierarchy process (AHP) approach have been found in the last decade ago. Lin et al.[9] applied the analytical hierarchy process in power lines maintenance. The main issue of this paper is to arrange for the power lines maintenance scientific and logical in the power department. Power lines maintenance is a complex process with many

influencing factors, which cover the knowledge of kinds of subjects, such as management, security, scheming and so on.

Dougligeris & Pereira [10] applied the analytical hierarchy process in a telecommunications quality study to solve the specific problem that the customer faced in choosing a telecommunication company that best specifies the consumers' needs. The evolution of technology has enabled the simultaneous cost reduction and quality improvement in the services offered. Customers have the opportunities to determine and purchase the quality of communication services that they need, by balancing their cost and value.

Kang & Seong [11] proposed a procedure for evaluating alarm-processing system regard to integrating a series of deviations in a nuclear power plant control room. Yang et al. [16] applied the analytic hierarchy process in location selection for a company. The location decision often depends on the type of business. For industrial location decision, the strategy is minimising the costs while for service organization, the strategy focuses on maximising revenue.

Frair, Matson & Matson [12] proposed an undergraduate curriculum evaluation with the analytic hierarchy process. A model of the problem for undergraduate curriculum designed is developed based on the responses from the affected parties (students, faculties, employers, etc.), curriculum components (design, science, math, etc.) and curriculum alternatives.

According to the above literature, it is found that the application of the analytical hierarchy process is widely used. It can be applied to power system [13], telecommunication [14], electrical and electronic [15], business [16], education [17], and so on. Table 2.2 shows the summarised information for the research projects related to the AHP.

Table 2.2: Summarised information for research projects related to AHP

Author(s) Year Field	Year	Field
Lin et al	2006	Power lines maintenance
Dougligeris & Pereira	1994	Telecommunications quality study
Kang & Seong	1999	Alarm-processing system
Yang et al	2008	Location selection
Frair, Matson & Matson	1998	Undergraduate curriculum evaluation

### 2.3 TOPSIS (Technique For Order Preference By Similarity to Ideal Solution)

TOPSIS is known as the “Technique for Order Preference by Similarity to Ideal Solution”. This method is a unique technique to identify the ranking of all alternatives considered. In the TOPSIS method, the decision making matrix and weight vector are determined as crisp values and a positive ideal solution (PIS) and a negative ideal solution (NIS) are obtained from the decision matrix [18].

In other words, PIS is a set of the best value of criteria while NIS is a set of worst values achievable of criteria. This method is applied to make wide-ranging evaluation of samples where it measured the distances between the index value vector of each sample and ideal solution along with the negative ideal solution of the comprehensive evaluation [18].

Hwang and Yon [19] are the first who introduces the TOPSIS method. Hwang and Yon describe multiple decisions making as follows: multiple decisions making is applied to the preferable decision (such as assessment making priorities and choices) between available classified alternatives over the multiple attributes or criteria. It assumes that each criterion requires to be maximised or minimised. Therefore, the ideal positive and negative values of each criterion are identified, and each alternative judge against this information.

It is noted that, in this typical multiple criterion decision making (MCDM) approach, weights of attributes reflect the relative importance in the decision making

process. Each evaluation of criteria entails diverse opinions and meanings. Hence, the assumption that each evaluation criterion is equally important is prohibited [20].

TOPSIS method consists of two artificial alternatives hypothesis, which are ‘Ideal Alternative’ and ‘Negative Ideal Alternative’. ‘Ideal Alternative’ represents the best level of all attributes considered while the ‘Negative Ideal Alternative’ represented the worst attributes values. With these two hypotheses, sets of calculations using eigenvector, square rooting and summations to obtain a relative closeness value of the criteria tested. These values of relative closeness, TOPSIS ranked the whole system by selecting the highest value of the relative closeness as the best attributes in the system.

Krohling & Campanharo [21] did a case study of accidents with oil spill in the sea by using TOPSIS approach. Wang et al. [21] applied TOPSIS to supplier selection. Sun & Lin [22] used TOPSIS for evaluating the competitive advantages of shopping websites. Wang & Chang [23] developed an approach in evaluating initial training aircraft under a fuzzy environment for the Taiwan Air Force Academy. Chamodrakas & Martakos [24] applied TOPSIS method for energy efficient network selection in heterogeneous wireless networks. Table 2.4 shows the summarized information for the research projects related to the TOPSIS.

Table 2.3: Summarised information for research projects related to TOPSIS

Author(s) Year Field	Year	Field
Krohling & Campanharo	2011	Accidents with oil spill in the sea
Wang et al.	2009	Supplier selection
Sun & Lin	2009	Competitive advantages of shopping online
Wang & Chang	2007	Initial aircraft training
Chamodrakas & Martakos	2011	Heterogeneous network selection



## 2.4 Pulp Mill Electrical System General Information [25]

Pulp mill is one of the heavy industries that consumes large amount of electricity in its production. In particular, the breakdown of generator would cause others generators to be overloaded. Thus load shedding scheme is the best way in handling such condition. Selected load will be shed under this scheme in order to protect the generators from being damaged. In the meantime, the subsequence loads will be shed until the generators are sufficient to provide the power to other loads. In order to determine the sequences of load shedding scheme, Analytic Hierarchy Process (AHP) and Technique For Order Preference By Similarity to Ideal Situation (TOPSIS) are used. AHP and TOPSIS are the multi-criteria decision making methods.

In pulp mill, there are quite a number of areas of land being used to allocate the equipment and device. The electrical system must be well managed in order to ensure that the operation in the mill is fully utilized. However, there might be breakdown in the electrical system due to the longer working period of the machines. The malfunction of the equipment or devices might cause huge losses to the company. Due to this, the load shedding scheme is needed in the pulp mill to prevent damage of the power generator.

The mill electrical voltage levels are divided into several categories such as:

- (i) 3-phase, 50Hz voltage level is divided to:

High voltage : 110kVac

Medium voltage : 35kVac and 6kVac

Low voltage : 690Vac and 400Vac

- (ii) 3×Turbine generator:  $2 \times 120\text{MW} + 90\text{MW} = 330\text{MW}$  connected to the public grid with 80MVA transformer but limited import to 60MVA due to shortage power in the grid.

Total load installed in a mill wide is about 249MW (including the redundant units). The estimated highest operating load capacity is about 158MW and normal



operating load is 130MW at 3,000 air-dried tons per day (adt/d) of production capacity.

The electrical load shedding coverage is focused on 35kV incoming feeders to each plant which excludes 35kV feeder to boiler and water treatment plant and 6kV motor feeders in each mill and arranged the priority table with manual and automatic options (excluded 690Vac incoming feeder due to huge cost additional). Notes: 6kV include in the load shedding system only for monitoring and the 6kV Smart Motor Control Center (MCC) is a conventional type. This is the purpose to gather the most information.

In order to design the pulp mill's electrical load shedding Supervisory Control and Data Acquisition (SCADA) system, the person in charge must have basic knowledge and process concept of a pulp mill and is required to work closely with process department. In addition, he/she must be capable to plan for an integrated system to fulfill the plant process and electrical distribution stability needs, and possesses the knowledge of the behaviour of a Steam Turbo Generator (TG) or electrical system and mill wide control system.

For example, the Load Shedding System should consist of a pulp storage tank with level indication. This is to decide when part of the mill should start the load shedding as it depends on the load and priority if TG trips, boiler trips or if some fault disturbing the stability of system frequency. The purpose of electrical load shedding SCADA system is to provide mill wide load shedding to stabilize the power distribution system during any abnormal circumstances, collect information for maintenance, diagnostic and historical purposes, ON-OFF control for the switcher, metering purposes and etc.

This is an important part of mill wide electrical system because the technology, which combines the electrical system, communication system with fully digitalised information of protection relay is for maintenance convenience. Two operation modes of load shedding are:

- (i) Island mode (disconnect to the public grid)
- (ii) Parallel mode (connects to the public grid)

### 2.4.1 Island mode [25]

The load shedding on island mode with 2 circumstances is designed:

- (a) 110kV bus bar frequency, as the frequency is directly related to a turbine generator turning speed. If the frequency drops, the turbine is overloaded and the steam will be insufficient or internal fault occurred and causes frequency dip.
- (b) Tripping of the turbine generators, the electrical system will immediately lose electricity not less than 40MW (During this condition, the other turbine running the generator is not able to cover the load in a short duration but will manage to take 10~15MW and another 20MW from the public grid). At such condition, the load shedder cannot depend on the busbar frequency due to slow responses but can depend on the setting made in the column of the TG trip. All settings will be done by the process engineer according to the mill production conditions or the automotive cyclic calculation and trip loads as per TG's power losses. This concept is convenient for the engineers during emergency cases.

### 2.4.2 Parallel mode [25]

The overall function of load shedding is similar to the island mode but the only deviation is that the frequency-based load shedding function will be deactivated (the reason is the public grid system is too huge compared to the electrical mill system which is only 330MW. Therefore, any disturbance from the external system will affect the mill system tremendously. So the decoupling protection relay setting at Gas Insulated Substation (GIS) – 140-ES is the critical point that protects the mill system from external factors.)

For example, if the feeder connected to the public grid senses huge outflow of current from the plant, the protection relay of the feeder will isolate the system within 15 minutes.

This is to avoid the mill wide electrical system from interruption due to heavy external fault occurred in public overhead transmission line. The load shedding will be activated and the load will be isolated according to the supply lost from the public grid.

Most cases that caused the load shedding function to activate were due to the tripping of recovery boilers. Recovery boiler is the main steam generator to produce about 60% of the electricity. If the recovery boiler trips, the steam will reduce rapidly.

The operators need to act fast to start the load shedding function manually (as it has not tripped the turbine generator yet) in order to keep the turbine generator to continue running.

Initially, the operation of the mill was unable to be saved due to lack of knowledge and experience of the load factor. However, after training is provided, the operator in charge can act wisely and promptly.

Normally within 10 minutes, the operator is able to manage and communicate with each plant to do the load shed selection manually to prevent the TG frequency to drop to 48Hz and to trip the generator by the turbine generator protection system. This helps to ease the pressure of production loss.



## CHAPTER 3

### METHODOLOGY

#### 3.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) was developed by Professor Thomas L. Saaty in the 1970s and has been extensively studied and refined since then [26]. It is a method for solving complex decision making based on the alternatives and multiple criteria, as it names stated. It is also a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria.

Nowadays, there are many versions of AHP existed. Originally, AHP was designed to calculate the  $n$ th root of the product of the pair-wise comparison values in each row of the matrices and then normalizes the aforementioned  $n$ th root of products to get the corresponding weights [26]. Meanwhile the modified AHP version normalizes the pair-wise comparison values within each of the matrices and then averages the values in each row to get the corresponding weights and ratings [26].

However both versions give almost the same results. For this research, the original method has been chosen to be implemented as the Multi Criteria Decision Making. Generally process of AHP analysis can be shown in three main steps.

**Step 1: Develop the weights for the criteria:**

- a) First, develop a single pair-wise comparison matrix for the criteria as shown in the equation below:

$$A_c = \begin{matrix} & \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{matrix}, i=1,2,\dots,n; j=1,2,\dots,n \quad (3.1)$$

where,  $C_1, C_2, \dots, C_n$  representing the criteria,

$a_{ij}$  represents the rating  $C_i$  with respect to  $C_j$

- b) Then, multiply the values in each row together and calculates the  $n^{\text{th}}$  root of the said product as shown in the equation below:

$$n^{\text{th}} \text{ root of product} = \sqrt[n]{\text{product of each row}} \quad (3.2)$$

Where  $n$  = positive integer number

- c) After that, normalizing the aforementioned  $n^{\text{th}}$  root of products to get the appropriate weights by using the formula given in equation 3.3:

$$\text{weight} = \frac{n^{\text{th}} \text{ root of product}}{\sum (n^{\text{th}} \text{ root of product})} \quad (3.3)$$

- d) Lastly, perform the Consistency Ratio (CR) by using the formula as shown below:

e)

$$CR = \frac{CR}{RI} \quad (3.4)$$

The value of Random index (RI) can be found using Table 3.1 where Random Index (RI) is a constant and it is a standard for AHP analysis.

Table 3.1: Table of Random index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

\*Note: Value of C.R must be less than the allowable value of 0.10. Therefore, the consistency of the judgment matrix should be within an acceptable tolerance. But if the consistency ratio is greater than 0.10 then the subjective judgment needs to be revised.

While the value for Consistency Index (CI) can be found by using this equation:

$$CI = \frac{\text{Lambda\_Max} - n}{n - 1} \quad (3.5)$$

And for Lambda\_Max,

$$\text{Lambda}_{\text{Max}} = \frac{\sum (\sum \text{column}_{\text{each alternative}} \times \text{weight}_{\text{per row}})}{n} \quad (3.6)$$

where:  $\sum \text{column}$  is the summation of pair-wise values of each alternative vertically and  $n$  is a positive integer number.

## Step 2: Develop the ratings for each decision alternative for each criterion

- First, develop a pair-wise comparison matrix for each criterion, with each matrix containing the pair-wise comparisons of the performance of decision alternatives on each criterion as shown in equation 3.7 below:

$$A_A = \begin{matrix} & \begin{matrix} A_1 & A_2 & \dots & A_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} & \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{matrix}, i = 1, 2, \dots, n; j = 1, 2, \dots, n \quad (3.7)$$

where  $A_1, A_2, \dots, A_n$  represent the alternatives,  $a_{ij}$  represents the rating of  $A_i$  with respect to  $A_j$

- b) Secondly, multiply the values in each row together and calculates the  $n^{\text{th}}$  root of the said product by using equation 3.8 below:

$$n^{\text{th}} \text{ root of product} = \sqrt[n]{\text{product of each row}} \quad (3.8)$$

Where  $n$  = positive integer number

- c) Then, normalizing the aforementioned  $n^{\text{th}}$  root of product values to get the corresponding ratings by using equation 3.9 below:

$$\text{weight} = \frac{n^{\text{th}} \text{ root of product}}{\sum (n^{\text{th}} \text{ root of product})} \quad (3.9)$$

- d) Lastly, perform the Consistency Ratio (CR) using equation 3.10 below:

$$CR = \frac{CI}{RI} \quad (3.10)$$

The value of Random index (RI) can be found using Table 3.1 below where

Random Index (RI) is a constant and it is a standard for AHP analysis.

Table 3.1: Table of Random index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

\*Note: Value of C.R must be less than the allowable value of 0.10. Therefore, the consistency of the judgment matrix should be within an acceptable tolerance. But if the consistency ratio is greater than 0.10 then the subjective judgment needs to be revised.

While the value for Consistency Index (CI) can be found by using this equation:

$$CI = \frac{\text{Lambda\_Max} - n}{n - 1} \quad (3.11)$$

And for Lambda\_Max,

$$\text{Lambda}_{\text{Max}} = \sum (\sum \text{column}_{\text{each alternative}} \times \text{weight}_{\text{per row}}) \quad (3.12)$$

where:  $\Sigma_{column}$  is the summation of pair-wise values of each alternative vertically and  $n$  is a positive integer number.

**Step 3: Calculate the weighted average rating for each decision alternative. Choose the one with the highest score**

- a) First, find the final score for each of the alternative. The final score for each alternative is the summation of the product of criteria to alternative.
- b) Generally, there will be  $n$  number of overall weight and  $n$  must be an integer that does not exceed 9. Therefore by using the formula given by equation 3.13 below the value for each decision alternative can be found:

$$Final\_score_{alternative X} = (Criterion A \times Alternative X) + (Criterion B \times Alternative X) + (Criterion C \times Alternative X) + \dots + (Criterion I \times Alternative X) \quad (3.13)$$

where *Criterion A* = 1st criterion, *Criterion B* = 2nd criterion, ..., *Criterion I* = 9th criterion and  $1 \leq X \leq 9$

The methodology can be simplified by using flowchart as shown in Figure 3.1. It is much easier to understand since generally it explains step by step process to implement AHP method. While in Figure 3.2, 3.3 and 3.4 show in details every step that must be implementing to reach the final objective.



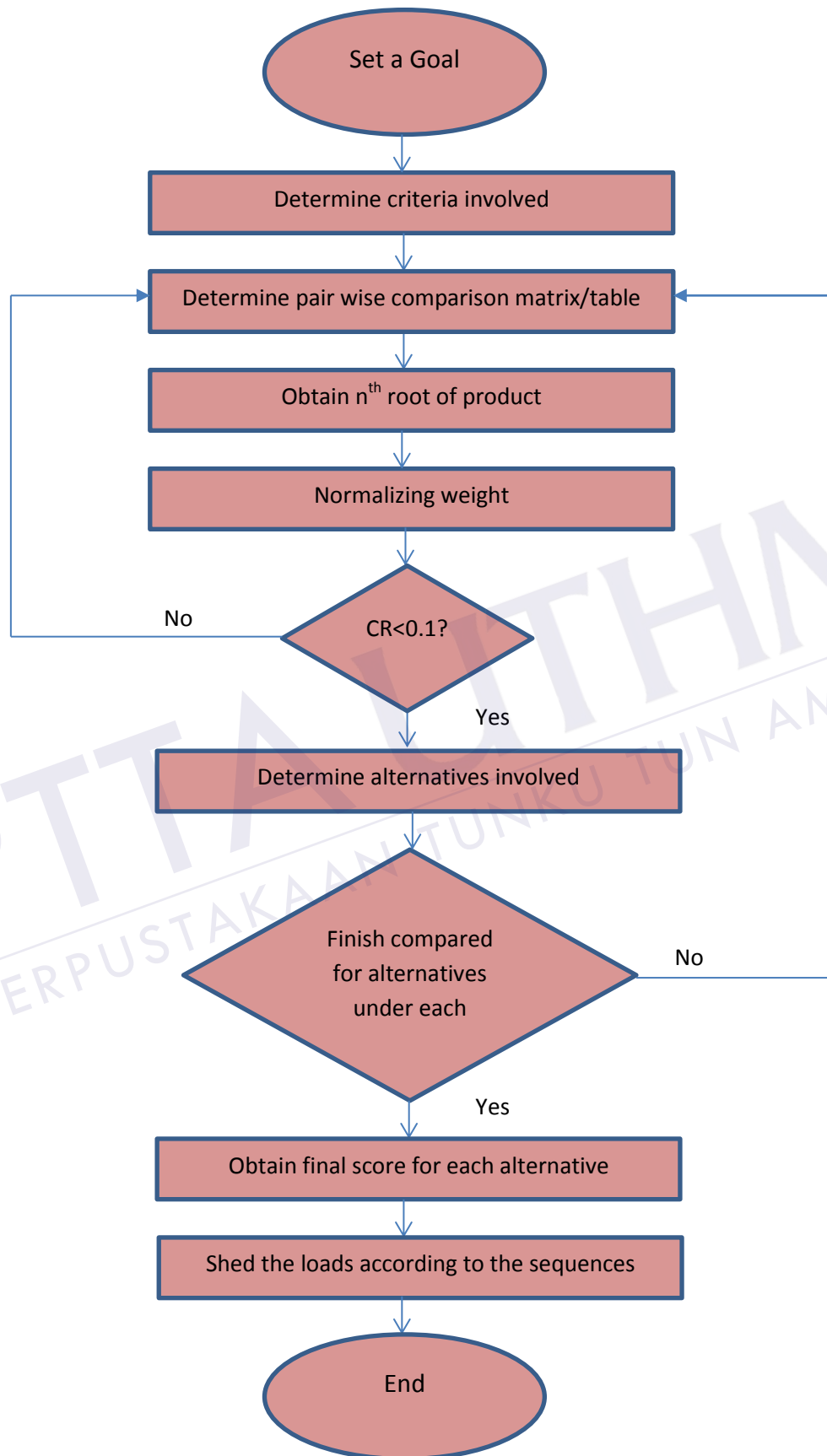


Figure 3.1: Flowchart for AHP Method

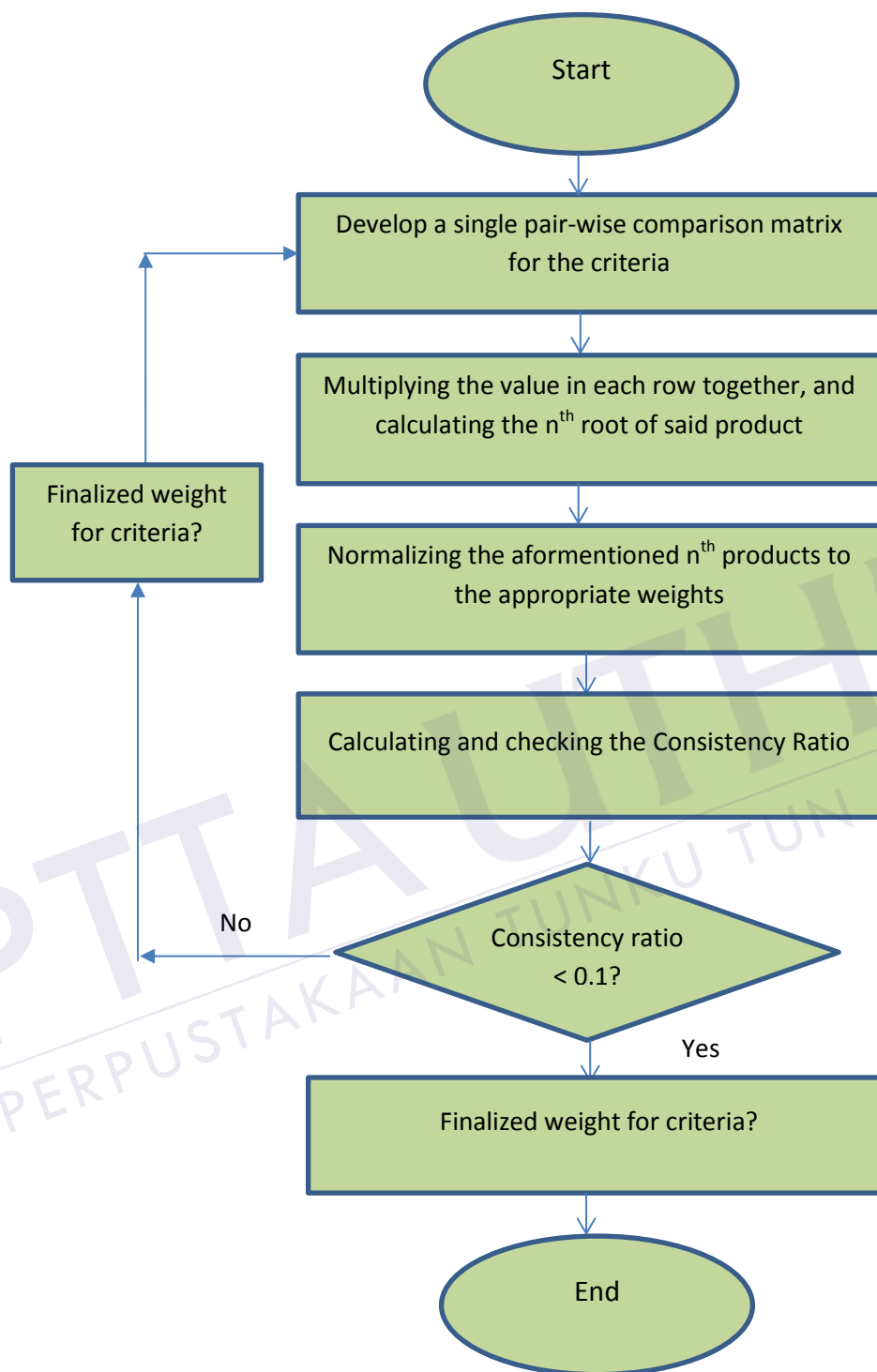


Figure 3.2: Step 1 in AHP method

## REFERENCE

- [1] Jethwa, U.K., Bansal, R.K., Date, N., Vaishnav, R.. Comprehensive Load-Shedding System. IEEE Transactions on Industry Applications. 2010. 46(2): 740-749.
- [2] Li, C., Sun, Y., Jia, Y., Li, H.. An Improved Ranking Approach to AHP Alternatives Based on Variable Weights. 7th World Congress on Intelligent Control and Automation. June 25-27th 2008. Chongqing:China. 2008. pp.8255-8260.
- [3] Suruhanjaya Tenaga. Interim Report on the Performance of the Electricity Supply Services in Malaysia for the first half year of 2010. Malaysia: An Interim Report.
- [4] Shokooh, F., Dai, J. J., Shokkoh, S., Tastet, J., Castro, H., Khandelwal, T. & Donner, G.. An Intelligent Load Shedding (ILS) System Application in a Large Industrial Facility. Industry Applications Conf, 2005. Fourtieth IAS Annual Meeting Conf. Record of the 2005, 1. 2005. pp. 417 - 425.
- [5] Ghaleh, A.P., Sanaye-Pasand, M., Saffarian, A.. Power system stability enhancement using a new combinational load-shedding algorithm. IET Generation, Transmission & Distribution. 2010. 5(5):551-560.

[6] Ozdagoglu, A. & Ozdagoglu, G. (2007). Comparison of AHP and Fuzzy AHP for the Multi-criteria Decision Making Process with Linguistic Evaluations. Retrieved on March 26, 2010 from

<http://www.iticu.edu.tr/Kutuphane/dergi/f11/M00178.pdf>

[7] Goh, H. H. & Kok, B. C.. Application of Analytic Hierarchy Process (AHP) in Load Shedding Scheme for Electrical Power System. 2010 9<sup>th</sup> International Conference on Environment and Electrical Engineering (EEEIC). 2010. pp. 365 - 368.

[8] Saaty, T. L. The Analytical Hierarchy Process. Mc Graw Hill, New York. 1980

[9] Ling, C.U.. Analytical Hierarchy Approach for Load Shedding Scheme of an Islanded Power System. Master Thesis. Universiti Tun Hussein Onn Malaysia:2012.

[10] Triantaphyllou, E. and Mann, S.H.. Using the Analytic Hierarchy Process For Decision Making in Engineering Applications: Some Challenges. International Journal of Industrial Engineering: Applications and Practice. 1995. 2(1): 35-44.

[11] Goh HH, Kok BC. A unique load shedding application in a large pulp mill electrical system. Int Conf Environ Electri Eng 2010.

[12] Palaniswamy KA, Sharma J, Misra KB. Optimum Load Shedding taking into account of Voltage and Frequency Characteristic of Load. IEEE Trans Vol Power Apparatus Syst 1985;PAS-104:1342–8.

[13] Perumal Ir N, Chan CY. A proposed strategy of implementation for load shedding and load recovery with dynamic simulations. In: National Power & Energy Conference (PECon) 2004, IEEE Explore; 2004. p. 185–9.

[14] Worawat N, Istvan E. Optimal load shedding for voltage stability enhancement by ant colony optimization. International conference on intelligent system application to power systems. World Academy of Science, Engineering and Technology; 2009. p. 1003–8.

[15] Cai GL, Zhang YJ, Cai ZX, Yu, T. A corrective load shedding control scheme to prevent voltage collapse. In: International Power Engineering Conference (IPEC 2007), IEEE Explore; 2007. p. 817–21.

[16] Arya LD, Singh P, Titare LS. Differential evolution applied for anticipatory load shedding with voltage stability considerations. International Journal of Electrical Power & Energy Systems 2012;42:644–52.

[17] Hooshmand R, Moazzami M. Optimal design of adaptive under frequency load shedding using artificial neural networks in isolated power system. Int J ElectroPower Energy Syst 2012;42:220–8.

[18] Karimi M, Mohamad H, Mokhlis H, Bakar AHA. Under-Frequency Load Shedding scheme for islanded distribution network connected with mini hydro. Int J Electr Power Energy Syst 2012;42:127–38.

[19] Giroletti M, Farina M, Scattolini R. A hybrid frequency/power based method for industrial load shedding. Int J Electr Power Energy Syst 2011;35:194–200.

[20] Yu TB, Zhou JZ, Zhao K, Wang W, Wang WS. Study on project experts' evaluation based on analytic hierarchy process and fuzzy comprehensive evaluation. In: International conference on intelligent computation technology and automation, IEEE explore; 2008. p. 941–5.

[21] Loken E, Botterud A, Holen Arne T. Decision analysis and uncertainties in planning local energy systems. In: International conference on probabilistic

method applied to power systems KTH, Stockholm, Sweden, IEEE Explore; 2006.

[22] Cheng E, Li H, Ho D. Analytic hierarchy process (AHP). Measuring business excellence bradford 2002;6:33–8.

[23] Dashti Z, Pedram MM, Shanbehzadeh J. A multi-criteria decision making based method for ranking sequential patterns. In: International multi conference of engineers and computer, scientist; 2010.

[24] Dan Xue, Zhao QL, Guo XY. TOPSIS method for evaluation customer service satisfaction to fast food industry, IEEE Explore; 2008. p. 920–5.

[25] L. S. T. Alpo, “Mega-sized pulp mill sets new standard for economies of scale,” Results pulp & paper 2009/2 ed. vol. 2010, 2009.

[26] Hwang CL, Yoon K. Multiple attribute decision making methods and applications. New York: Springer-Verlag; 1981.

[27] Wang TC, Lee HD. Developing a fuzzy TOPSIS approach based on subjective weight and objective weights. Expert system with applications, science, direct 2008. p. 8980